TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 706

AN EXPERIMENTAL INVESTIGATION OF THE NORMAL ACCELERATION OF AN AIRPLANE MODEL IN A GUST

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SUMMARY

In order to provide experimental data as a check of the theories used in the prediction of applied loads on airplanes due to atmospheric gusts, an investigation was made in the N.A.C.A. gust tunnel to determine the influence of the airplane wing loading, the forward velocity, the wing plan form, and the fuselage on the reaction of the airplane to a known gust. Tests were made for four values of gust velocity and for two gust gradients, namely, the sharp-edge gust and a gust rising linearly to full strength in a distance of several chord lengths.

The results of the investigation indicate that the formulas given in a 1937 S.A.E. paper by R. V. Rhode entitled "Gust Loads on Airplanes" predict the qualitative effect of gust velocity, forward velocity, wing loading, wing plan form, and gust gradient on the acceleration increment in a satisfactory manner. The quantitative agreement is also good for airplanes of normal proportions when the fuselage is neglected in the computations; i.e., when the wing area intercepted by the fuselage is included as a part of the wing. Although the agreement between computed and test results remained good for aspect ratios as low as 2.0, there is an indication in Technical Note No. 682 that, in some cases, the influence of the finite span may require more careful consideration.

The investigation also shows that the value of maximum lift coefficient for steady flow does not limit the acceleration increment in a gust.

INTRODUCTION

In recent years, the importance of the applied wing loads due to atmospheric gusts has increased. In order to obtain fundamental data on the magnitude of these loads, statistical measurements of accelerations and speeds (reference 1) were obtained during flight in rough air. Theoretical studies (reference 2) of the response of an airplane when a gust is encountered in flight were also published.

In regard to the theoretical studies of the reaction of an airplane to a gust, much progress has been made. The first analyses of gust loads on airplanes were based on the simple sharp-edge gust formula, which is derived in reference 1. Küssner's contribution (reference 2) removed some of the more severe limitations of the simple formula by including the influence of lift lag and the vertical motion of the airplane. For the practical solution, the equations of reference 2 were solved, certain simple gust shapes being assumed; the results are given in reference 3. Based on Wagner's classical work (reference 4), a recent paper by Jones (reference 5) has introduced additional refinements in unsteady-lift theory to account for the effect of finite span on the development of lift. Other research workers (reference 6) have attempted to refine the theory still further by removing other restrictions utilized by Küssner in his original work.

Although much progress has been made in acquiring flight data on applied loads and in formulating theories, little or no information is available to verify the correctness of the theoretical studies. Some few tests made for flutter investigations, such as reference 7, can be used as a check of the basic unsteady-lift theory. The work of Walker (reference 8), made to verify Wagner's classical study, is probably the best check of the basic two-dimensional theory available to date. In no case, however, has any work been done that would yield reliable data to verify the theory of Küssner, as set forth in reference 2 and summarized in reference 3, or any other theory which attempts to predict the reaction of an airplane due to a known gust.

In order to investigate experimentally the problems of gust loads, the N.A.C.A. designed and constructed the gust-tunnel apparatus. The apparatus is arranged so that dynamically scaled airplane models can be flown through gusts of known shapes and intensities. During a traverse of the gust, the reactions of the airplane models are measured.

The present investigation was undertaken to make an experimental survey of the influence of airplane and gust characteristics on the maximum acceleration increment of an airplane encountering a gust, particularly with reference to equations (3) and (4) of reference 3. The tests were arranged to cover the influence of the following factors on the reaction of an airplane to a gust:

1. Gust velocity.
2. Forward velocity.
3. Wing loading.
4. Wing plan form
5. Gust gradient.

It was hoped that, from a few tests for a number of widely different conditions, a check of the more important aspects of the various theories would be obtained. In this way, the results would indicate the most promising lines of attack for future studies, theoretical and experimental, and would offer experimental data to check present design practices for applied loads due to gusts.

The tests were performed in the N.A.C.A. gust tunnel at Langley Field during the fall and winter of 1937-1938. A few additional tests to answer minor questions arising during the tests were made during the summer of 1938.

APPARATUS AND INSTRUMENTS

Gust-tunnel apparatus.- Figure 1 shows a diagram of the gust tunnel and the auxiliary apparatus. The apparatus comprises the gust tunnel, a catapult, and two screens to decelerate and catch the airplane model at the end of the flight. Other equipment consists of cameras and spotlights used in recording the motion of the airplane model as it traverses the gust.

The gust tunnel itself (fig. 1) consists of a large squirrel-cage blower supplying air to an expanding rectangular channel, which discharges a current of air upward. The flight path of the airplane model is through this jet of air. The jet of air, 6 feet wide and 8 feet long, is controlled in speed by varying the blower revolution speed and in shape by suitable screening in the mouth of the tunnel. The combinations of 16 and 30 mesh screen used to obtain the desired gust shapes were obtained by trial and the resulting velocity distributions were measured by a carefully calibrated hot-wire anemometer. The velocity distributions of the gust jet at the height at which the model flies are shown in figure 2.

When the airplane completes its traverse of the gust tunnel, the wing encounters the screen of vertical rubber strands indicated in figure 1. As the model penetrates the screen, it is decelerated until the speed is just sufficient to make the barbed hook (fig. 3) penetrate the screen of burlap. The barbed hook catches in the burlap screen and holds the model until removed by the operator.

The catapult (fig. 1) consists of a small carriage riding on a track of two taut cables. The apparatus is so arranged that the track angle to the horizontal is adjustable. Propulsion is effected by means of a dropping weight and the maximum speed can be adjusted from zero to 80 feet per second by changing the amount of this weight. The model is supported on the carriage, in an attitude corresponding to the tail setting of the model, by a retractable thrust rod. The thrust rod applies the driving force to the model at the center of gravity and is arranged to retract clear of the model when flying speed is reached. The model is then free to glide over the gust tunnel.

Airplane models.- Figure 3 shows the general arrangement of a typical airplane model used in the tests. Figure 4 shows the four plan forms of the wings that were tested; the same fuselage was used. For the wings of high aspect ratio $(A > 6)$, the airplane models were arranged as shown in figure 3. When the wings of low aspect ratio shown in figure 4 were used, the longitudinal-stability requirements made an increase in tail length necessary. In order to lengthen the tail, a boom 10 inches long was fitted to the tail of the fuselage and the tail surfaces were placed on the end of this boom. For a series of special tests, the square-tip wing of aspect ratio 6.73 was fitted to a steel tube 5/8 inch in diameter to form a skeleton airplane. The characteristics of the resulting airplane model were approximately the same as those given in table I for the same wing with a wing loading of 1.02 pounds per square foot.

The standard aerodynamic characteristics for the tapered wing model were experimentally determined in the N.A.C.A. 5-foot vertical wind tunnel. The characteristics of the model with the rectangular wings of high aspect ratio were calculated from these tests by conventional methods. For the wings of low aspect ratio, the data of reference 9 were used. The airfoil section of all the wings was the N.A.C.A. 0012 airfoil (reference 10). The geometric and aerodynamic characteristics of the airplane models are included in table I.

A basic assumption of reference 3 is that the wing is rigid. As the results of the present tests were to be used to check the equations of reference 3, the airplane wings were made as rigid as possible. In order to obtain an indication of the actual rigidity, tests were made to determine the wing-deflection curves and the natural wing periods in bending. The natural periods of the wings have been included in table I and the wing-deflection curves are shown in figure 5. The deflection curves for the wings of low aspect ratio have not been included because, under normal values of load, the wing deflection was less than the error of measurement (0.01 in.).

Instruments.- Records of the normal acceleration, the flight path, the attitude, and the flying speed of the airplane model were obtained from a small photographically recording accelerometer carried in the fuselage of the model and by small lamps at the nose and the tail of the fuselage as shown in figure 3. The accelerometer makes a record of the normal-acceleration increment as the model traverses the gust. The lamp paths are photographed by two cameras (fig. 1) and show the variation in attitude and flight path as the model traverses the gust. The speed of the model is obtained by interrupting the path lines recorded on one camera by a rotating shutter.

Sample records obtained from these instruments are shown in figure 6. In the record from the accelerometer (fig. 6(a)), the portion obtained while the model was going through the gust is indicated by the double-headed arrow. The vertical line, seen to the left of the gust record, is made when the model flies through a narrow beam of light and serves to synchronize the accelerometer record with the records of flight path and attitude.

Figure 6(b) shows the record obtained of flight path and attitude just before entry into the gust. The dashed lines represent the interruption of the path lines by the rotating shutter and are a measure of the speed of the airplane model.

Figure 6(c) is the record of flight path and attitude of the model airplane as it traverses the gust. The deviation of the path from straight lines indicates the vertical motion of the airplane model. The distance between the two path lines is a measure of the attitude and the pitch of the airplane model as it traverses the gust.

TESTS

The tests were arranged to cover the influence of variations of gust velocity, gust gradient, forward velocity, wing loading, wing plan form, and fuselage interference on the acceleration increment due to a gust. The attempt was made to test each variable, holding all others constant, but in many cases this attempt was impossible. In all cases, unless otherwise noted, tests were made for the sharp-edge gust.

<u>Gust velocity</u>.- The effect of gust velocity on the acceleration increment is, of course, of great importance. For this reason, tests for all conditions (table I) were made for several gust velocities (2 to 10 f.p.s.) except for flights at low forward speed, which will be mentioned later. Inspection of preliminary test results, obtained during the development and adjustment period of the catapult, indicated that it was impossible to prevent certain variations in test conditions. For this reason, at least five runs for each condition tested were made to obtain average values of the different quantities. This procedure applied to all tests made and for all conditions tested.

<u>Forward velocity</u>.- As in the case of the gust velocity, theory indicates that the forward velocity is of prime importance in its effect on the acceleration increment. Most of the tests were made at a speed of about 60 feet per second, the maximum speed that could be used and the model be still decelerated and caught without damage.

A few additional tests were made at a speed of 40 feet per second and a gust velocity of 6.5 feet per second. The Reynolds Number was usually between 125,000 and 180,000 but, for the tests at 40 feet per second, the Reynolds Number was about 85,000.

Wing loading.- The effect of wing loading on the acceleration increment was investigated for two wing plan forms. The tests were made with the rectangular wing of aspect ratio 6.73 and the tapered wing of aspect ratio 7.45. The weights of the airplane models were prescribed by the minimum weight at which the model could be made ready to fly and the maximum weight at which the model could be caught without damage when flying at 60 feet per second.

Wing plan form.- In reference 3 the effect of wing-tip vortices was neglected for finite spans. The changes in wing plan form considered in this investigation were variations in aspect ratio for similar wings and changes in wing taper and tip shape.

The tests to determine the effect of aspect ratio were made with the rectangular wings (fig. 4). Owing to the radically different aspect ratios used, it was impossible to hold all airplane characteristics constant (table I) but it was hoped that the other portions of the investigation would yield sufficient information to eliminate the effect of such variables from the results.

The tests to determine the influence of wing taper were made with the wings of normal aspect ratio shown in figure 4. The wing of the airplane model chosen was of moderate taper ratio because it was felt that tests for extreme tapers would introduce other variables, such as tip stalling. The tests for the effect of tip shape were made on the low-aspect-ratio wing, as wind-tunnel tests (reference 9) indicated a radical effect of tip shape on the slope of the lift curve for wings of this character.

Fuselage.- No information concerning the effect of a fuselage on the acceleration increment being available, a few tests to determine this effect were made. For this purpose, the skeleton airplane model was tested at one value of wing loading and forward speed. The tests made for other portions of the investigation also indicate, to a certain extent, the effect of fuselage as the wing area intercepted by the fuselage varies with wing chord for a given fuselage. The wing area intercepted by the fuselage was taken as zero for the skeleton wing. For the other fuselage-wing combinations used during this investigation, the fuselage intercept is given in table II as a percentage of the gross wing area.

Gust gradient.- In order to determine the effect of gust gradient on the acceleration increment, a few tests were made for the conditions noted in table I with a gust-gradient distance of 5.5 feet (fig. 2). Inasmuch as all other variables were held constant, the tests made in the sharp-edge gust with the lightly loaded rectangular wing of aspect ratio 6.73 were used for comparative purposes.

RESULTS

In general, records of all flights over the gust tunnel were evaluated to give histories of events occurring just prior to entering the gust and during the traverse of the gust. Sample results for each airplane and gust condition tested are shown in figures 7 to 10. The data shown in these figures have not been converted to nominal forward velocities.

In view of the purpose of this investigation, the most interesting results are the measured maximum acceleration increments for each test condition. The maximum acceleration increments were corrected to a nominal forward speed (60 f.p.s.) in all cases and the results are given in figures 11 to 16 where the maximum acceleration increments are shown as a function of the average maximum gust velocity. For purposes of comparison, there has been included in each figure the theoretical variation of maximum acceleration increment as a function of gust velocity computed from figure 17, which is a general solution of equations (3) and (4) of reference 3. The theoretical values shown have been based on the data given for each airplane model in table I.

The tests of the skeleton airplane, being of a special type, could not be evaluated to give histories of events because only the maximum acceleration increments and forward velocity were recorded. The results of these tests were therefore only maximum acceleration increments corrected to a forward velocity of 60 feet per second as a function of gust velocity. The results are shown in figure 15, together with the corresponding theoretical variation according to the method of reference 3.

PRECISION

The precision of the measurement of the various quantities is estimated to be within the following limits:

Acceleration increment - - - - - - - -	±0.05g
Forward velocity - - - - - - - - - - - -	±1 f.p.s.
Gust velocity - - - - - - - - - - - -	±0.1 f.p.s.
Attitude of airplane model - - - - - -	±0.1°
Pitch-angle increment of airplane model - - - - - - - - - - - - - - - - -	±0.1°
Vertical-displacement increment of airplane model - - - - - - - - - - - -	±0.01 ft.

Inasmuch as the error in measuring acceleration increments is absolute in character, the percentage error is, of course, increased as the acceleration increment is reduced. For this reason, it is felt that the recorded values shown in figures 11 to 16 for the acceleration increment at the lower gust velocities should be given less weight than data obtained when the value of the acceleration increment was much larger.

Inspection of the data of figures 11 to 16 discloses much greater variations in the measured quantities than can be ascribed to the listed errors. A study of the results showed that the variations are orderly, that is, higher accelerations correspond to higher vertical displacements. From consideration of these effects, it appears that the discrepancies noted are not caused by errors in the measurements as such but seem to be due to early technique, which has been improved since the conduct of these tests. More recent results show considerably less scatter of the data.

It is felt that, for the purpose of this investigation, the effect of wing flexibility can be treated as an error in measurement. The measurements of the wing deflections (fig. 5), combined with the measured acceleration increments for the most severe conditions, indicate a maximum error of about 4 percent in the acceleration increment for the tapered wing. For the other wings, which were stiffer, and for less severe gust conditions, the error is much less and is considered negligible for the purpose of the investigation.

The precision of the acceleration-increment measurements for the skeleton airplane warrants special consideration. As no accelerometer could be carried, the accelerations were assumed to be a function of the vertical displacement of the center of gravity of the airplane model at a given distance of penetration into the gust. This relation was determined by plotting all available data, from the other tests, of acceleration increment against vertical displacement. The results of this computation indicated a maximum scatter of the data of ±0.1g from the mean value and an average variation of the order of ±0.05g.

DISCUSSION OF RESULTS

Gust velocity.- Theory indicates that the maximum acceleration increment should be a linear function of gust velocity. In figures 11 to 16, the results indicate that this prediction is reasonably good, although slight nonlinearity is indicated in some cases.

Forward velocity.- The variation of the maximum acceleration increment with forward speed is linear, according to theory. In figure 11, data obtained on the rectangular wing of aspect ratio 6.73 at two forward speeds (60 and 40 f.p.s.) are shown, corrected in each case to 60 feet per second. The results indicate that the correction brings all the data into excellent agreement. This agreement indicates that theory predicts correctly the effect of forward velocity on the maximum acceleration increment. A further indication from the tests at 40 feet per second is that the normal value of $C_{L_{max}}$ does not limit the acceleration in a gust. This result is evident from the fact that the lift coefficient corresponding to the acceleration increment in these tests was 1.05, whereas the $C_{L_{max}}$ of the model determined at the same Reynolds Number in a special wind-tunnel test was only 0.81.

Wing loading.- In general, inspection of figures 11 and 12 indicates that, for rectangular and tapered wings, the theory predicts the effect of wing loading to a reasonable degree of accuracy. In order to arrange these data in a more convenient form for comparison with theory, a ratio was made of the acceleration increment for high wing loading to that for the lighter wing loading for the theory and experiment. When the information given in figure 11 for the rectangular wing was used, the value of this ratio was 0.70 for the theory and 0.67 for the average experimental data at large values of gust velocity. The corresponding ratios for the tapered wing (fig. 12) yield values of 0.73 and 0.69 for theory and experiment, respectively. This agreement is well within the errors involved in the experiments and the computations.

Wing plan form.- The influence of wing plan form on the maximum acceleration increment can be considered from two viewpoints; first, the effect of finite span or finite aspect ratio; and, second, the effect of changes in wing plan form, such as wing taper and tip shape. The effect of all such variations in plan form is to cause deviations of the air flow around the wing from the two-dimensional flow assumed in reference 2.

In the application of two-dimensional-flow computations to wings of finite span (reference 3), the influence of the tip vortices is neglected. In recognition of this factor in equations (3) and (4) of reference 3, the actual wing lift-curve slope was used in place of that for two-dimensional flow.

The extension of Wagner's classical work (reference 4) by Jones (reference 5) has permitted the development of new formulas corresponding to equations (3) and (4) of reference 3. The results of computations based on this development are shown in figure 17. The results are given. for a sharp-edge gust, of the acceleration ratio ($\Delta n/\Delta n_s$, where Δn_s is the acceleration increment of reference 1) as a function of the mass parameter, M. Figure 17 indicates that, for wings of aspect ratio greater than 6, the effect of tip vortices is small. Figure 17 indicates that, for all values of M, the discrepancy is appreciable for low-aspect-ratio wings. For wings of aspect ratio greater than or equal to 6, the discrepancy is negligible at low values of M and increases slowly with increasing M.

The experimental data (fig. 13) indicate fair agreement with reference 3, which is contrary to the preceding analysis. In view of this unexpected agreement, the corresponding theoretical curve (from fig. 17) was plotted on figure 13 to show the magnitude of the deviation. As will be explained later, the disagreement is attributed to a compensating effect due to the fuselage.

The effect of wing taper and tip shape is not treated by available theories as a variable but is accounted for (reference 2) by estimating their effect on the slope of the lift curve for steady flow. Inspection of figure 12 for the tapered-wing data indicates that the approximation is satisfactory, while figures 13 and 14 indicate the same conclusion for the influence of tip shape.

Fuselage.- None of the theories yielded predictions as to the influence of the fuselage on the acceleration increment for an airplane. It was first assumed, however, that the effect of the fuselage could be estimated by considering that the wing chord through the fuselage section was expanded to the length of the fuselage. Considering the fuselage as a wing, the assumptions of reference 3 indicate that the fuselage lift at maximum acceleration increment for the airplane would be negligible as compared with that of the wing. This conclusion is reached from the fact that the development of lift is a function only of the airfoil chord, according to reference 2. On this basis, then, the acceleration increments obtained for the models tested should fall below the computations based on reference 3 by an amount proportional to the wing area intercepted by the fuselage (table II).

Inspection of the data shown in figures 11 to 16 indicates no such variation. In particular, figures 11 and 15 for the conventional and the skeleton airplanes of comparable characteristics fail to show any appreciable effect that can be ascribed to the fuselage.

On consideration of the apparent discrepancies noted in the preceding paragraphs and under Wing Plan Form, it appeared that the effect of the fuselage might compensate for the effect of finite aspect ratio. In this case, the effect of the fuselage, as previously mentioned, was considered to reduce the lift near the start of the motion for the curves by an amount proportional to the fuselage intercept. The asymptotes would remain the same because, after an infinite time, the fuselage lift would reach its steady-flow value.

An analysis based on these assumptions indicates that the curve for $A = 2$ of figure 17 (curve C) would lie slightly above curve A. Curve B for $A = 6$ would also drop somewhat to lie closer to curve A. This fact would indicate that, for low-aspect-ratio wings, the effect of fuselage compensates for that of finite aspect ratio. This result is also shown by the adjusted curves of figures 13 and 14.

It is concluded from the previous discussion that, owing to the compensating effect of the fuselage on the plan form, the equations of reference 3 are satisfactory for conventional present-day airplanes. (Fig. 18 of the present report will probably be more convenient than the formulas of reference 3.) For unconventional airplanes, the more rational treatment based on reference 5 should be used.

<u>Gust gradient</u>.- The solution of reference 1 assumes that the pitch increment of the airplane is zero regardless of gust shape. The histories of events (figs. 7(a) and 10) indicate that this assumption is satisfactory for entry into a sharp-edge gust up to peak acceleration but is not satisfied for a gradient gust. Tests of the sharp-edge gust having shown that, in general, the theory gives satisfactory results, the significance of the gust shape appears to be in the failure of the assumption of zero pitch up to peak acceleration.

In reference 4, a study has been made of the effect of airplane stability in pitch on the acceleration increment, neglecting lift lag. The results of the study bear out the present tests in that, for a sharp gust, the effect of stability, and therefore of pitch, is negligible. The analysis also shows that, for gusts with gentle gradients, the effect of pitch is appreciable and depends on the dynamic stability of the airplane.

Inspection of figure 10 indicates that the pitch is appreciable for the airplane tested but, when the results in figure 16 are considered, no discernible influence of the pitch can be noted. An attempt was made to calculate the pitch and its effect on the increment of acceleration for the gradient-gust condition but the lack of data on the stability of the airplane model and the simplifications necessary to keep the computations within bounds precluded any accurate answers.

The limited amount of data and the complexity of the problem of predicting the effect of pitch on the acceleration increment indicate that more experimental data and study are necessary. It can be concluded, however, that the effect of a gradient gust is predicted in a satisfactory manner by the solution in reference 3 for the model tested.

CONCLUDING REMARKS

The effect of the following variables on the maximum-acceleration increment is predicted in a satisfactory manner for conventional airplanes of present design by the theory of reference 3:

1. Gust velocity.
2. Forward velocity.
3. Wing loading.
4. Wing plan form.
5. Gust gradient.

For unconventional airplanes, the application of reference 5 may be required.

For wings of normal aspect ratio, the effect of the fuselage can be neglected.

The maximum lift coefficient for a wing in steady flight is not the limiting value of the maximum lift coefficient for unsteady flow.

The assumption of zero pitch (reference 3) is fulfilled for the sharp-edge gust but not for the gradient gust.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 16, 1939.

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TABLE I

MODEL CHARACTERISTICS AND TEST CONDITIONS

Wing shape	Weight, W (lb.)	Wing area, S_W (sq.ft.)	Wing loading, W/S (lb. per sq. ft.)	Span, b (ft.)	Mean aerodynamic chord, c (ft.)	Aspect ratio	Center of gravity (percent of M.A.C.)	Natural wing period (sec.)	Slope of lift curve (per radian)	Moment of inertia (lb.-ft.^{2})	Mass parameter, $M = \frac{2W}{\rho a g S c} + \frac{1}{4}$	Acceleration ratio, $U_s = \frac{\Delta n}{\Delta n_s}$	Forward velocity (f.p.s.)
Square tip	1.975	1.337	1.48	3.0	0.446	6.73	25	0.0213	4.63	0.27	18.95	0.74	60
Do. . . .	1.29	1.337	.96	3.0	.446	6.73	25	.0213	4.63	.24	12.46	.70	60
Do. . . .	1.36	1.337	1.02	3.0	.446	6.73	25	.0213	4.63	.25	13.12	.71	40
[a]Do. . . .	1.36	1.337	1.02	3.0	.446	6.73	25	.0213	4.63	.25	13.12	.60	60
Do. . . .	1.56	1.309	1.19	1.67	.797	2.06	25	.0053	2.64	.29	15.03	.72	60
Circular tip	1.48	1.075	1.38	1.54	.702	2.18	25	.0053	2.90	.28	17.90	.74	60
Tapered	1.36	1.204	1.13	3.0	.405	7.45	25	.0167	4.73	.25	15.65	.72	60
Do. . . .	2.06	1.204	1.71	3.0	.405	7.45	25	.0167	4.73	.30	23.58	.76	60

[a]Tests made with gradient gust.

TABLE II

WING AREA INTERCEPTED BY FUSELAGE

Wing shape	Aspect ratio	Fuselage intercept (percent wing area)
Tapered	7.45	10.8
Square tip	6.73	9.7
Do.——	2.06	18.1
Circular tip	2.18	22.0

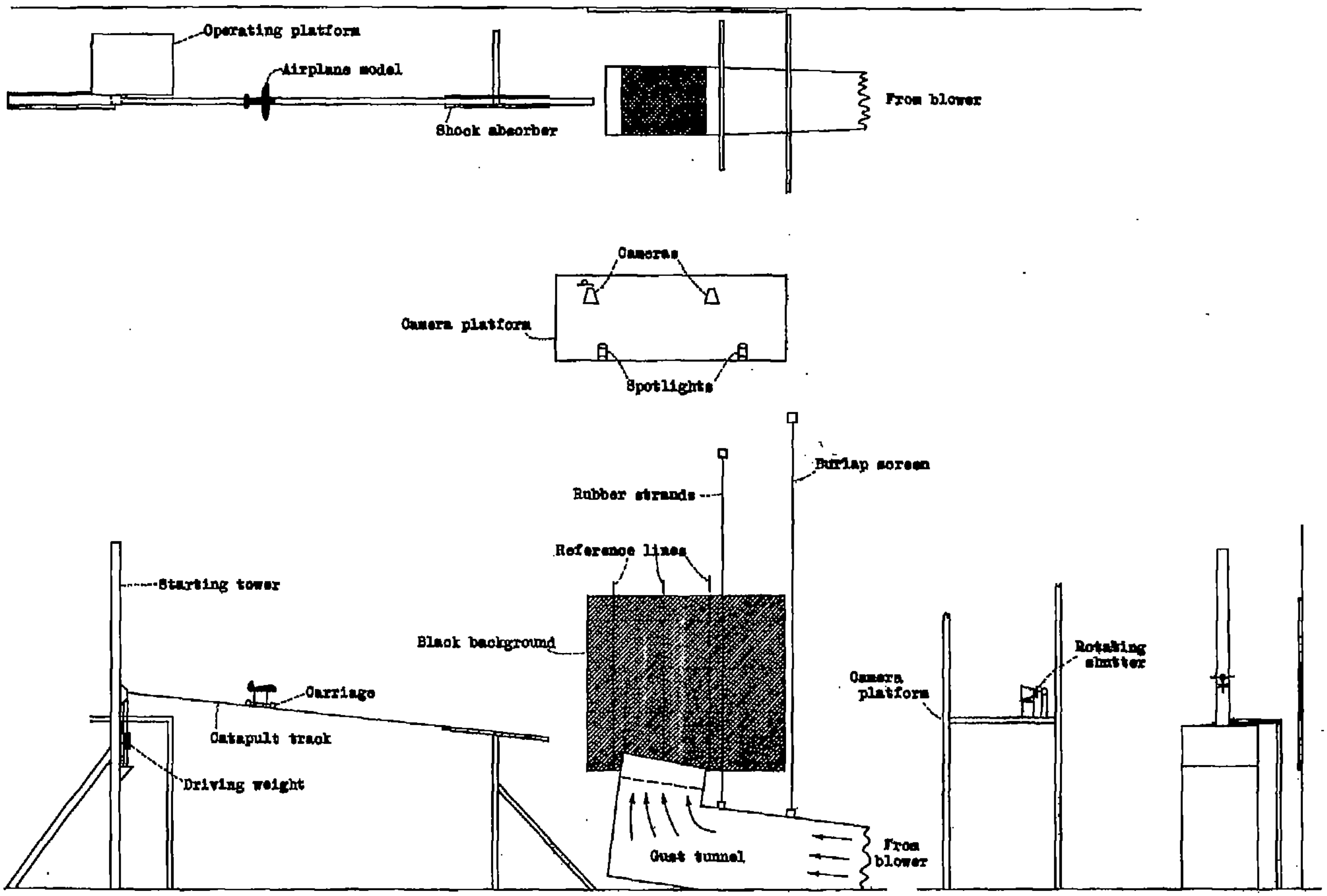


Figure 1.- Diagram of gust tunnel.

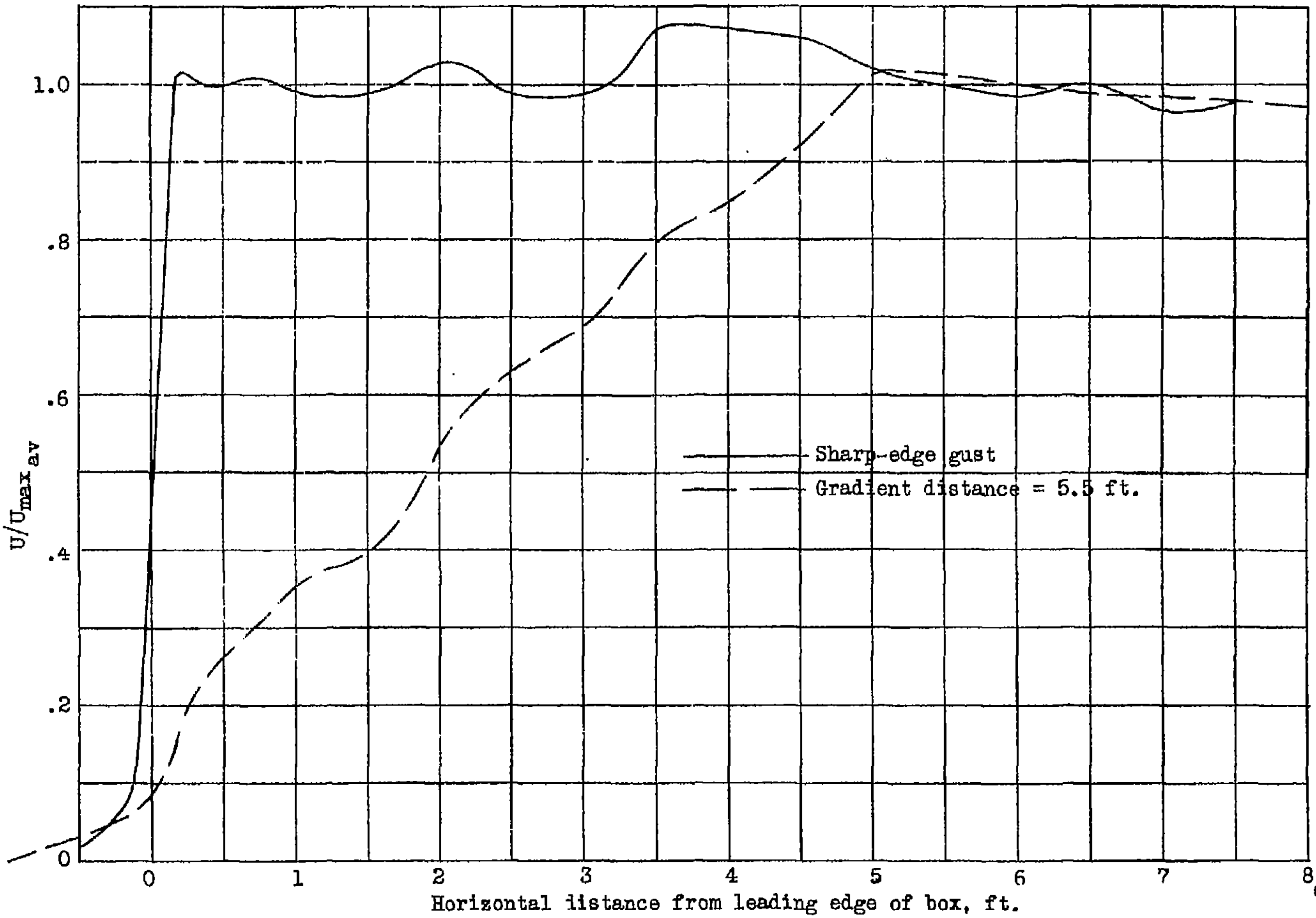
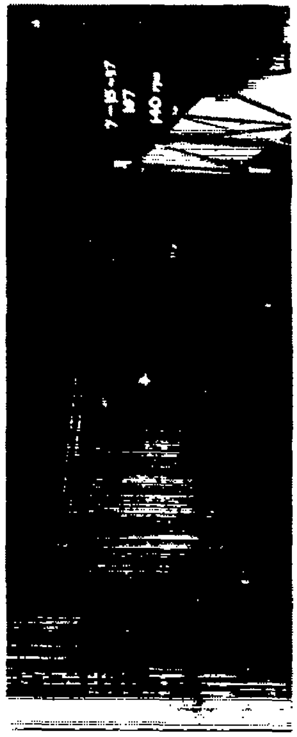
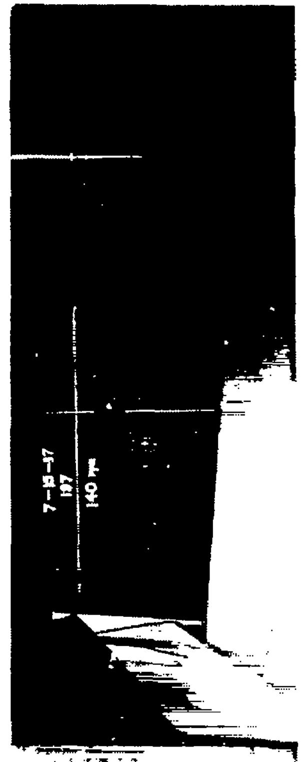


Figure 2.- Velocity distribution in gust tunnel.

(a) Accelerometer record.



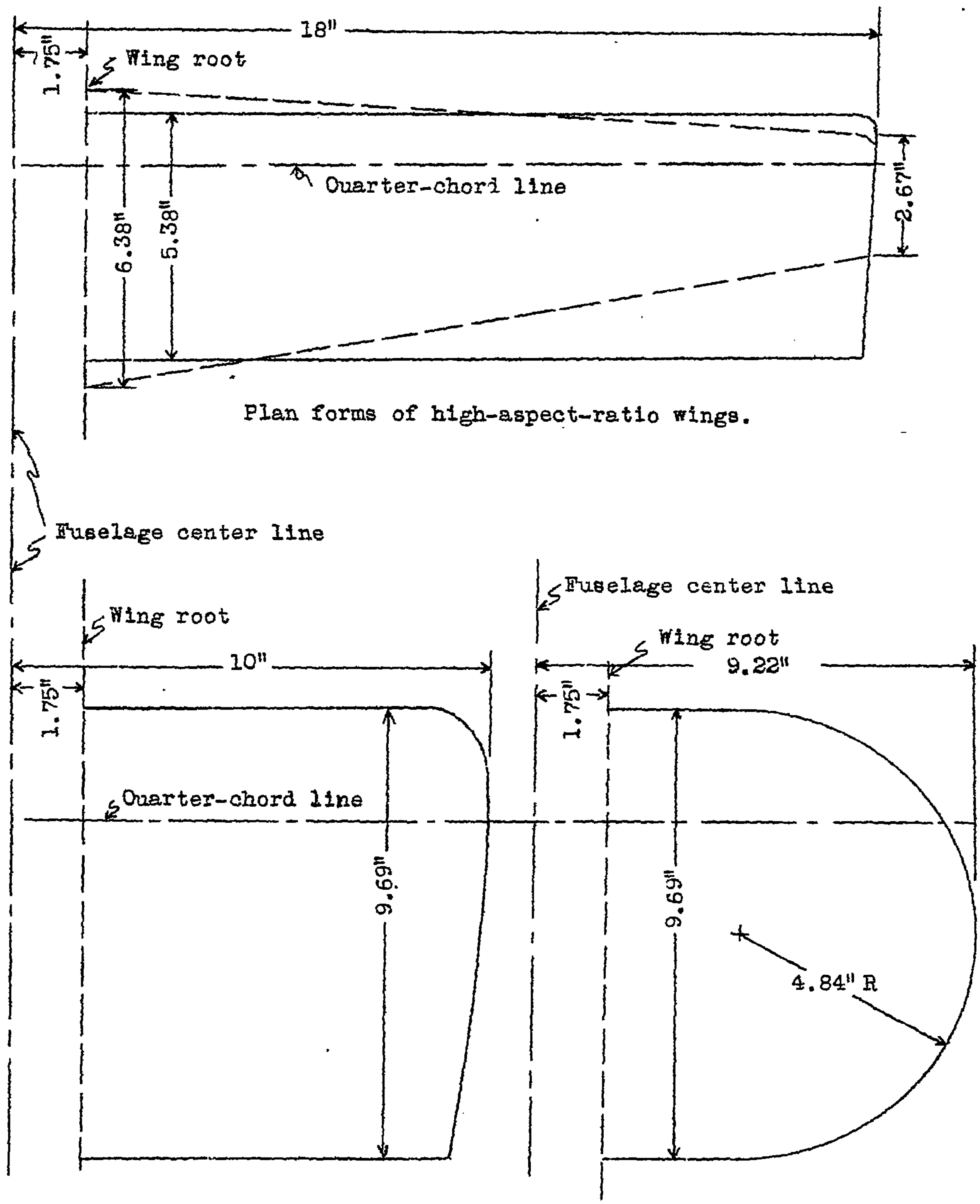
(b) Record of flight path and speed.



(c) Record of flight path.

Figure 6.- Sample records.

Figure 3.- Photograph of tapered wing model.



Plan forms of high-aspect-ratio wings.

Plan forms of low-aspect-ratio wings

Figure 4.- Wing plan forms used during investigation.

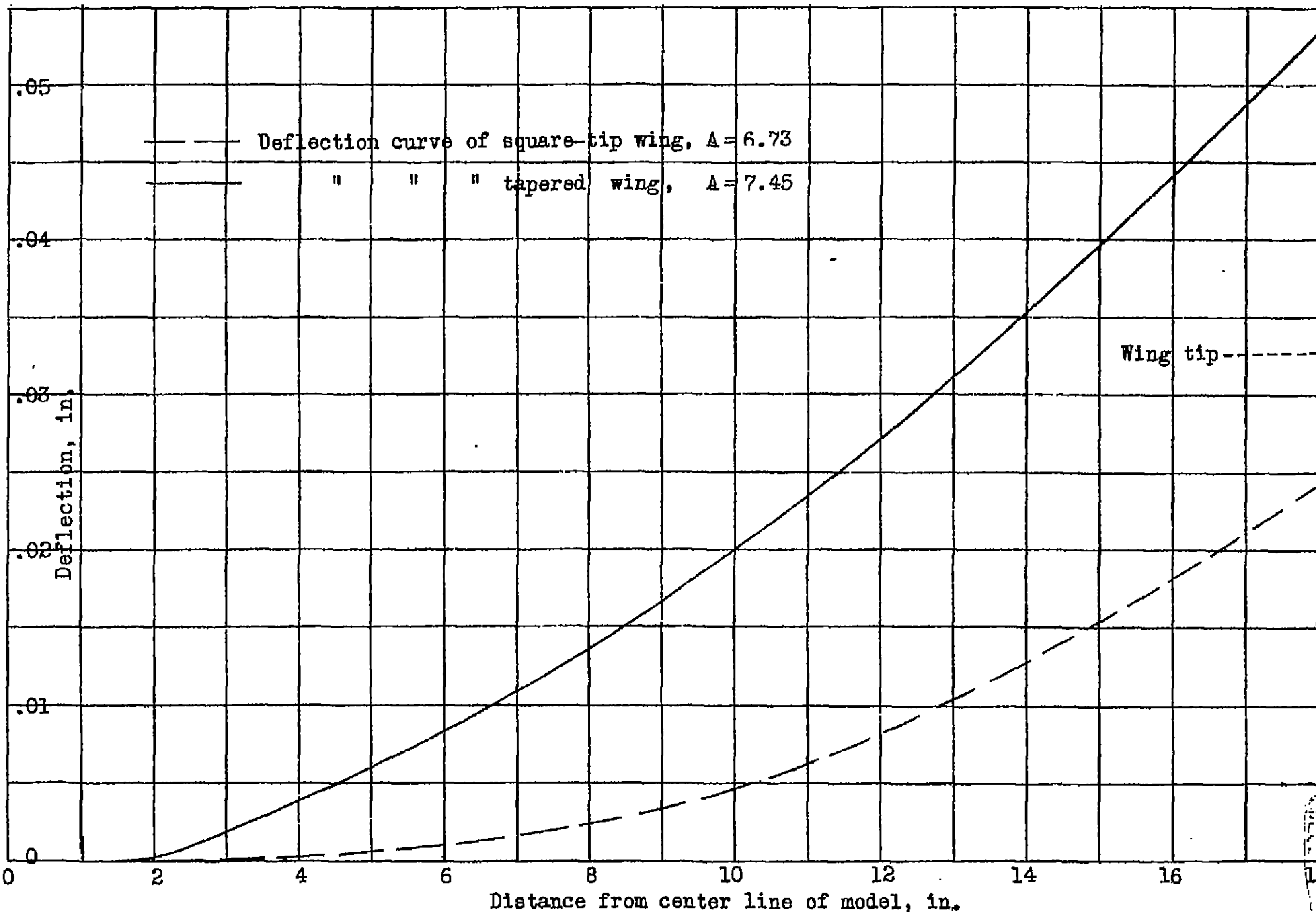


Figure 5.- Wing deflection for a total load of 1 pound.

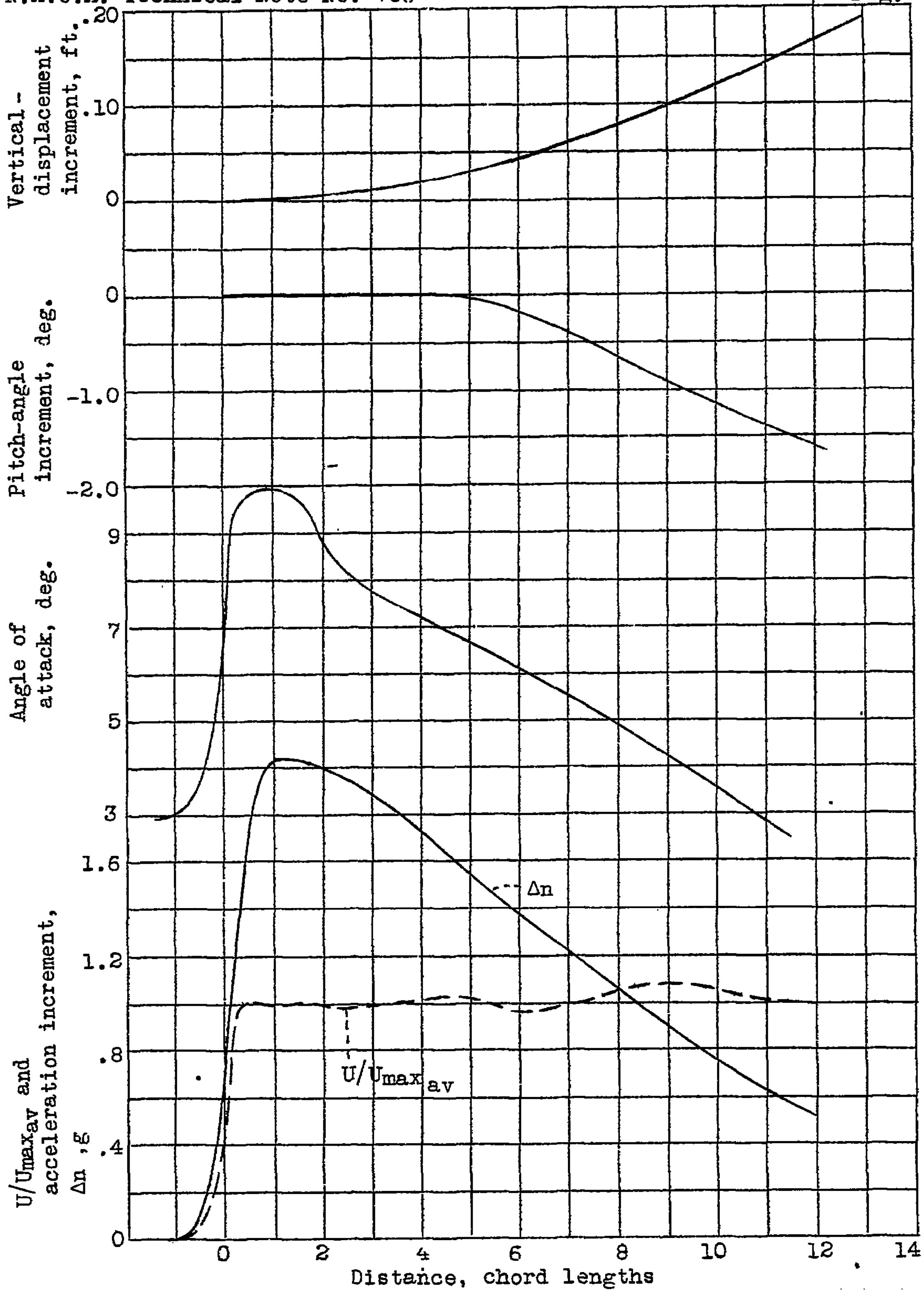


Figure 7a.- Histories of airplane motion for a square-tip wing in a sharp-edge gust, W/S, 0.96 lb./sq.ft.; A,6.73 .

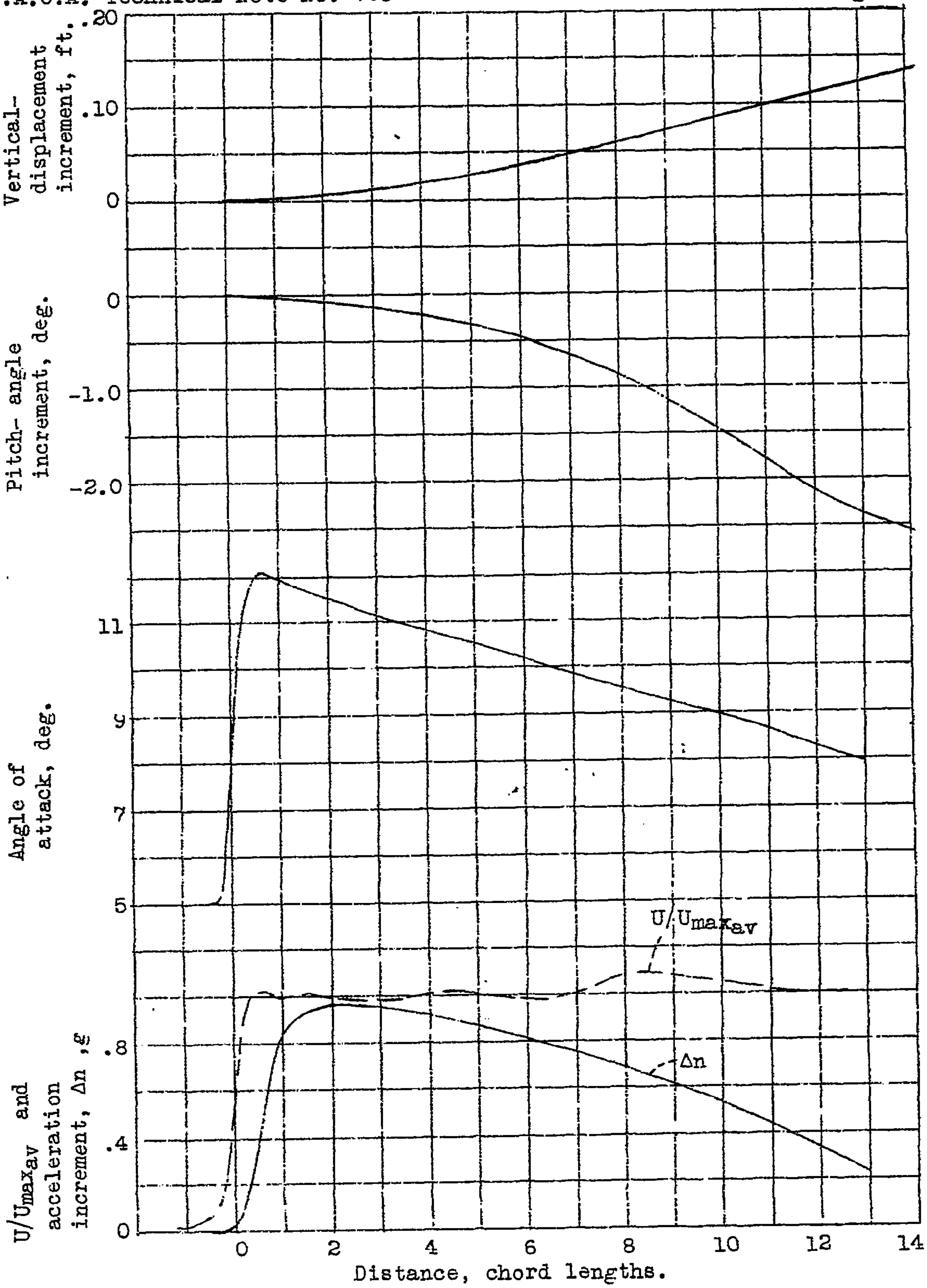


Figure 7b.- Histories of airplane motion for a square-tip wing in a sharp-edge gust. W/S, 1.48 lb./sq.ft.; A, 6.73 .

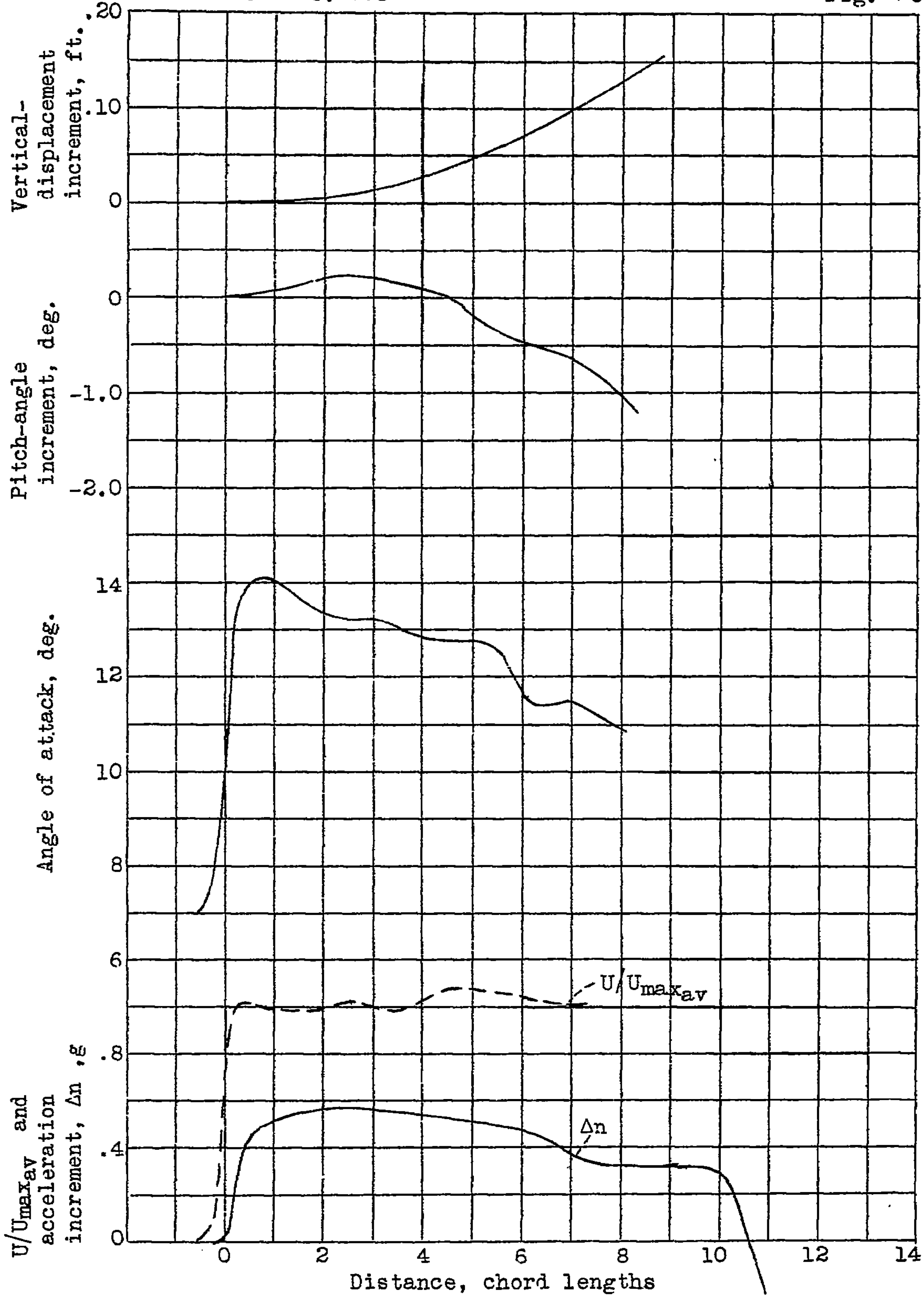


Figure 7c.- Histories of airplane motion for a square-tip wing in a sharp-edge gust, W/S,1.19 lb./sq.ft.; A,2.06.

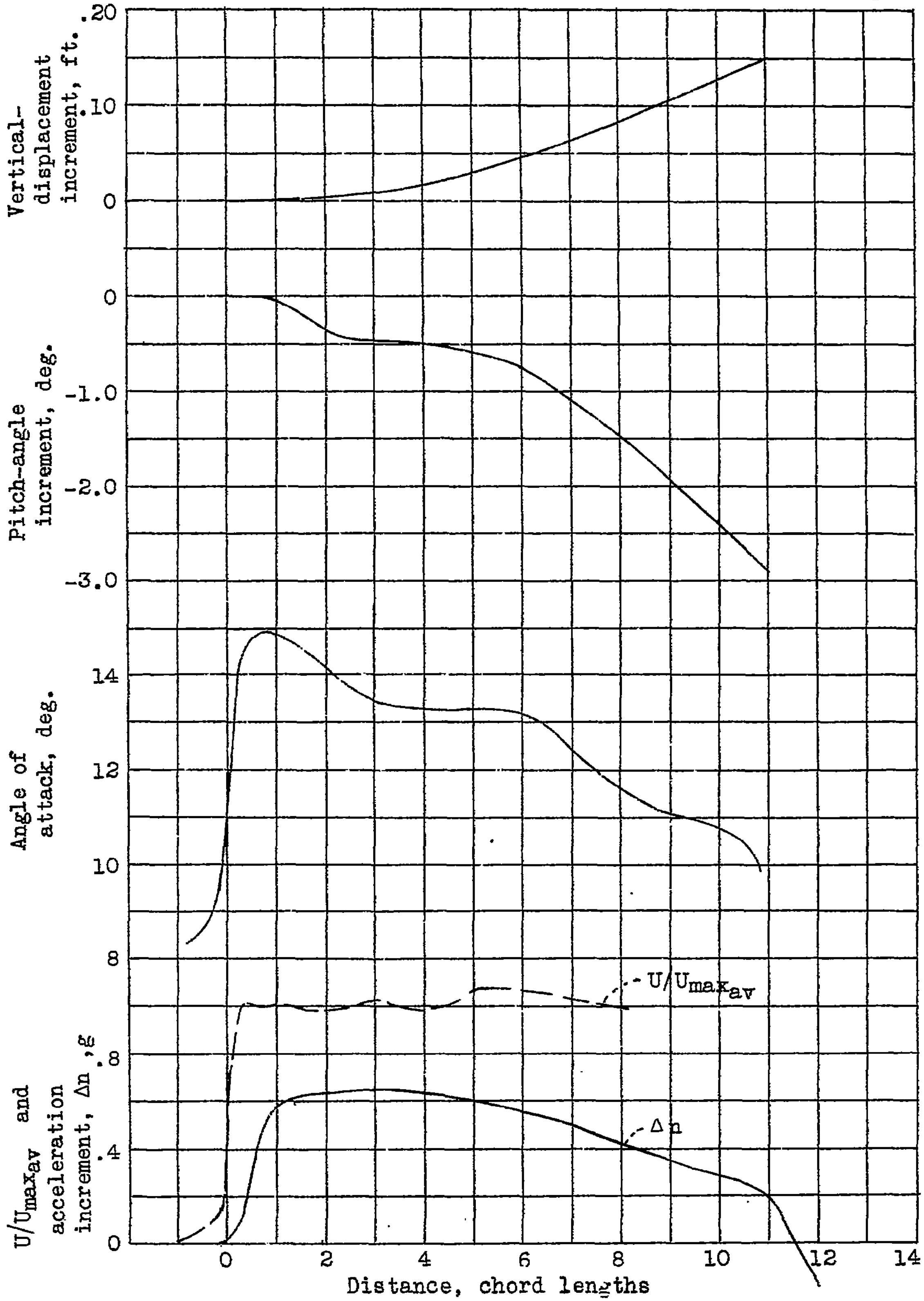


Figure 8.- History of airplane motion for a circular-tip wing in a sharp-edge gust. W/S, 1.38 lb./sq.ft.; A, 2.18 .

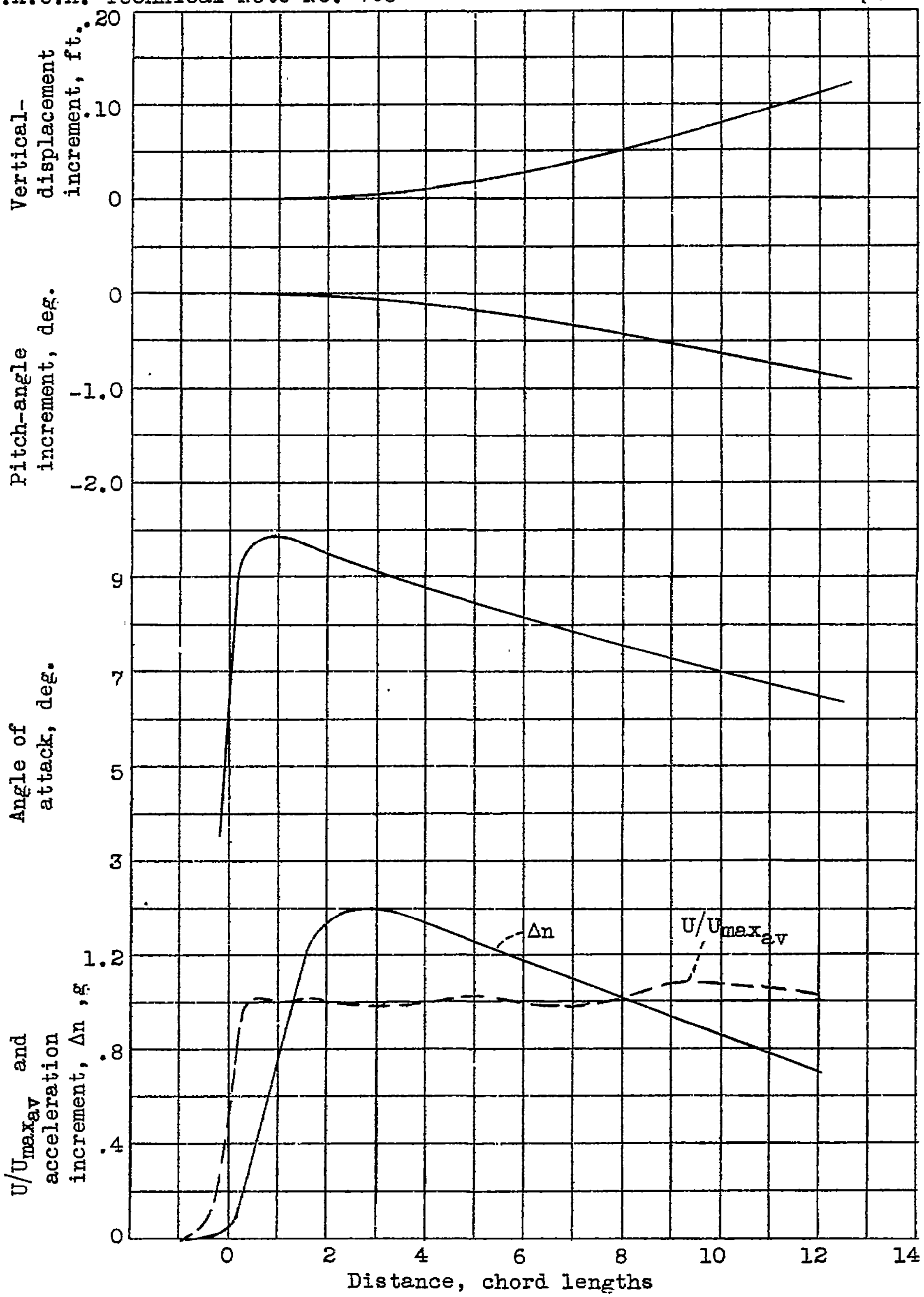


Figure 9a.- Histories of airplane motion for a tapered wing in a sharp-edge gust. W/S, 1.13 lb./sq.ft.; A, 7.45 .

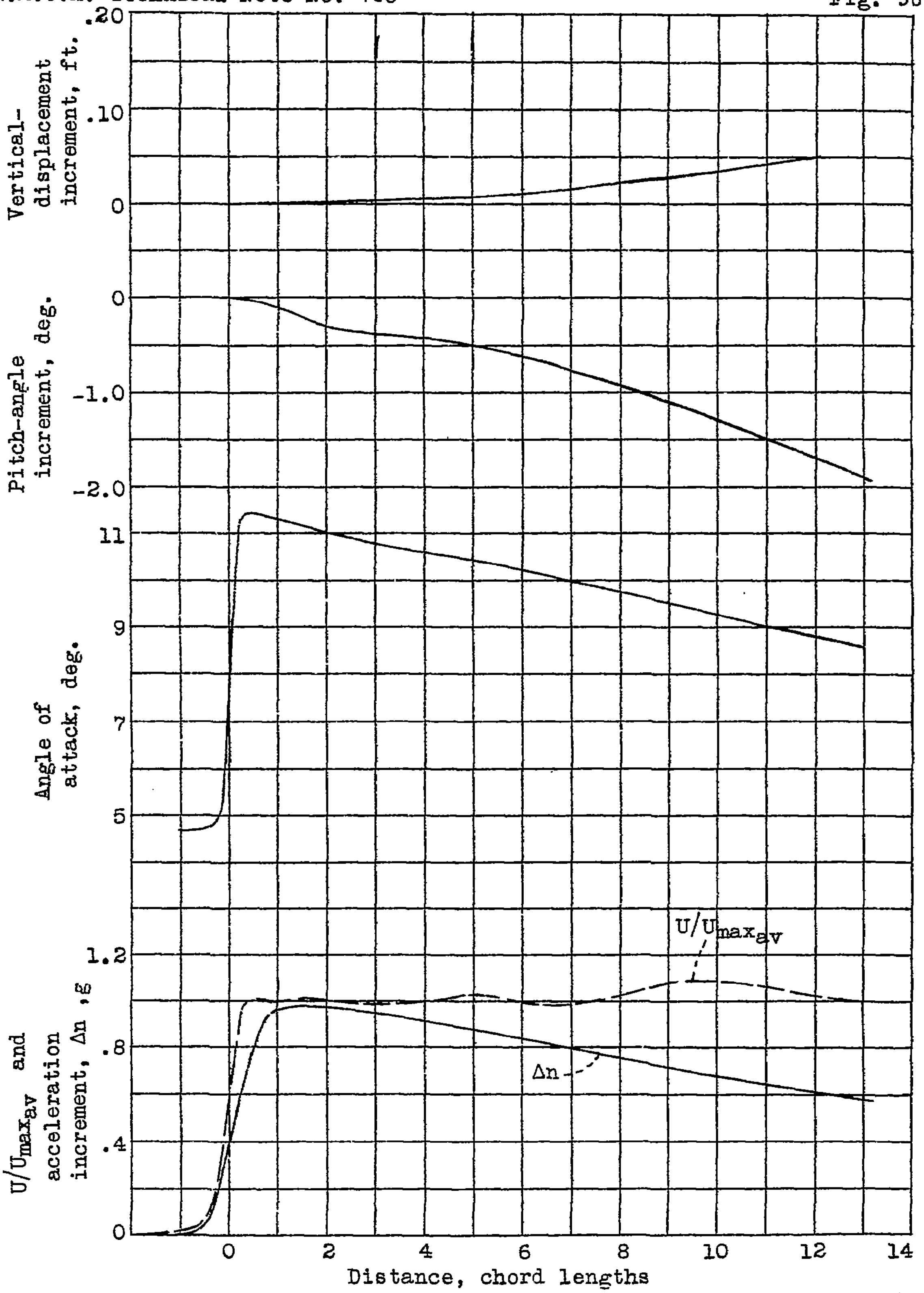


Figure 9b.- Histories of airplane motion for a tapered wing in a sharp-edge gust, W/S, 1.71 lb./sq.ft.; A, 7.45 .

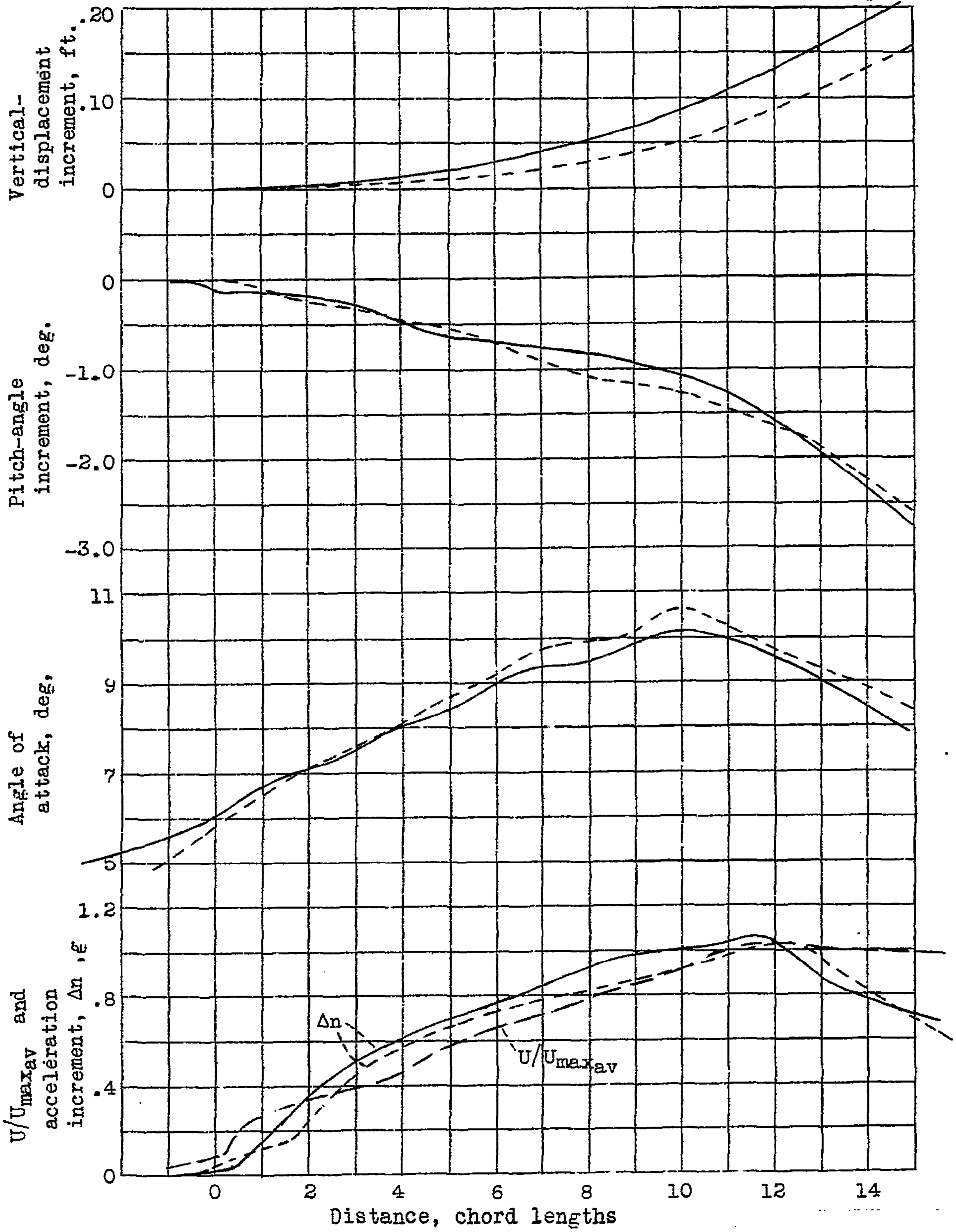


Figure 10.- Histories of airplane motion for a square-tip wing in a gradient gust, W/S, 1.02 lb./sq.ft.; A, 6.73

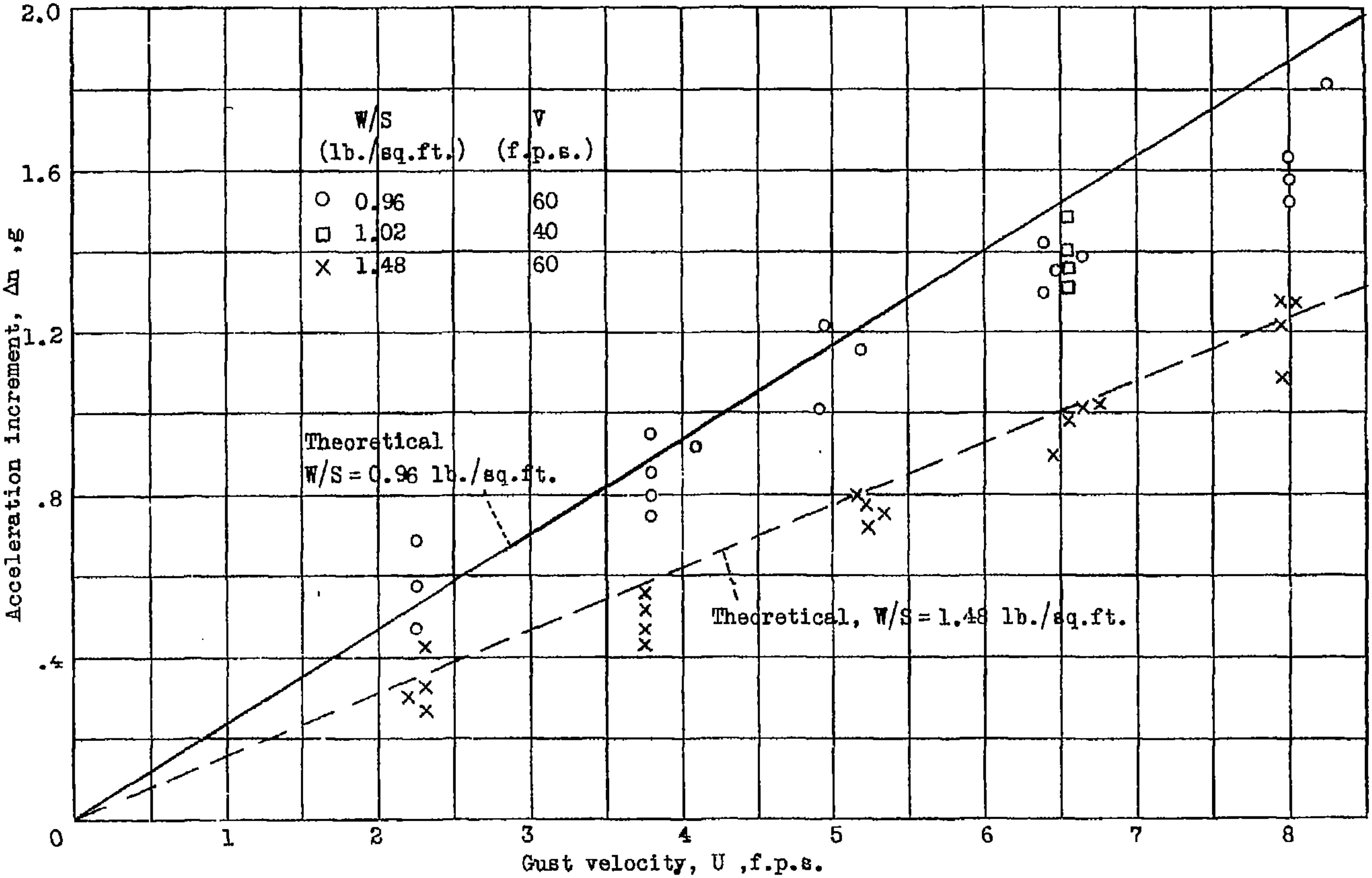


Figure 11.- Variation of acceleration increment with gust velocity. Square-tip wing; A,6.73; Sharp-edge gust.

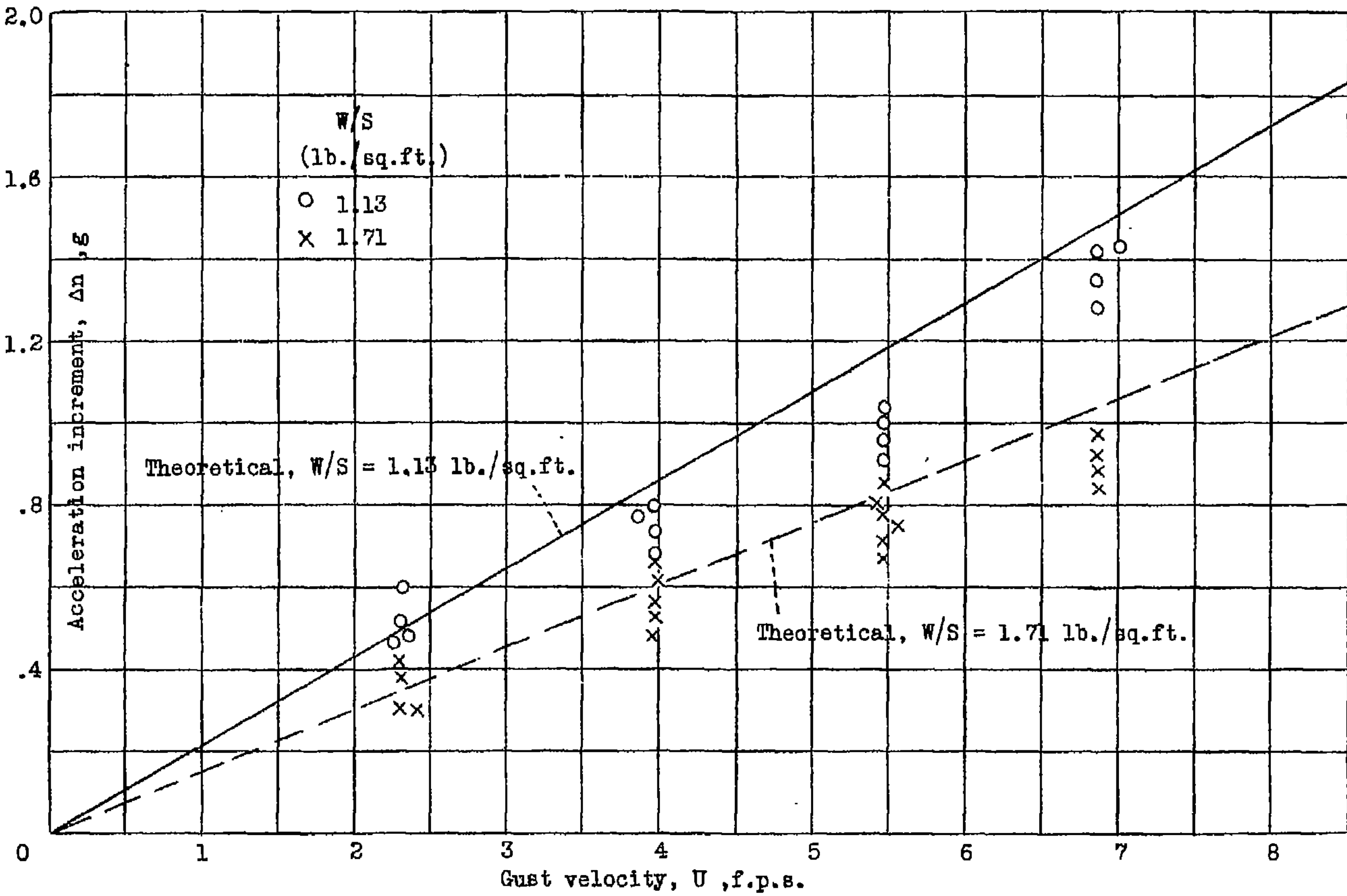


Figure 12.- Variation of acceleration increment with gust velocity. Tapered wing; A, 7.45; Sharp-edge gust.

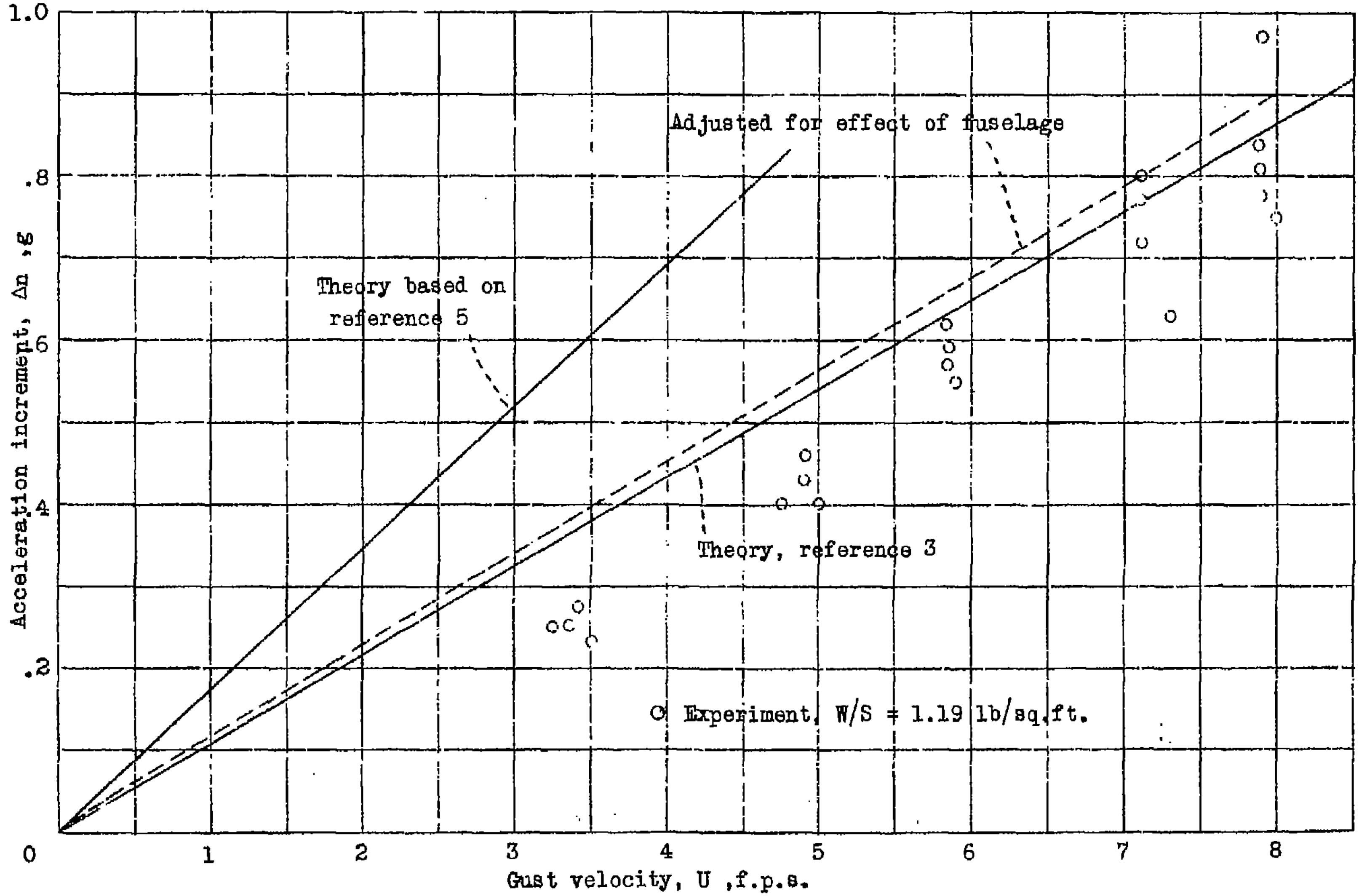


Figure 13.- Variation of acceleration increment with gust velocity. Square-tip wing, A,2.06, Sharp-edge gust.

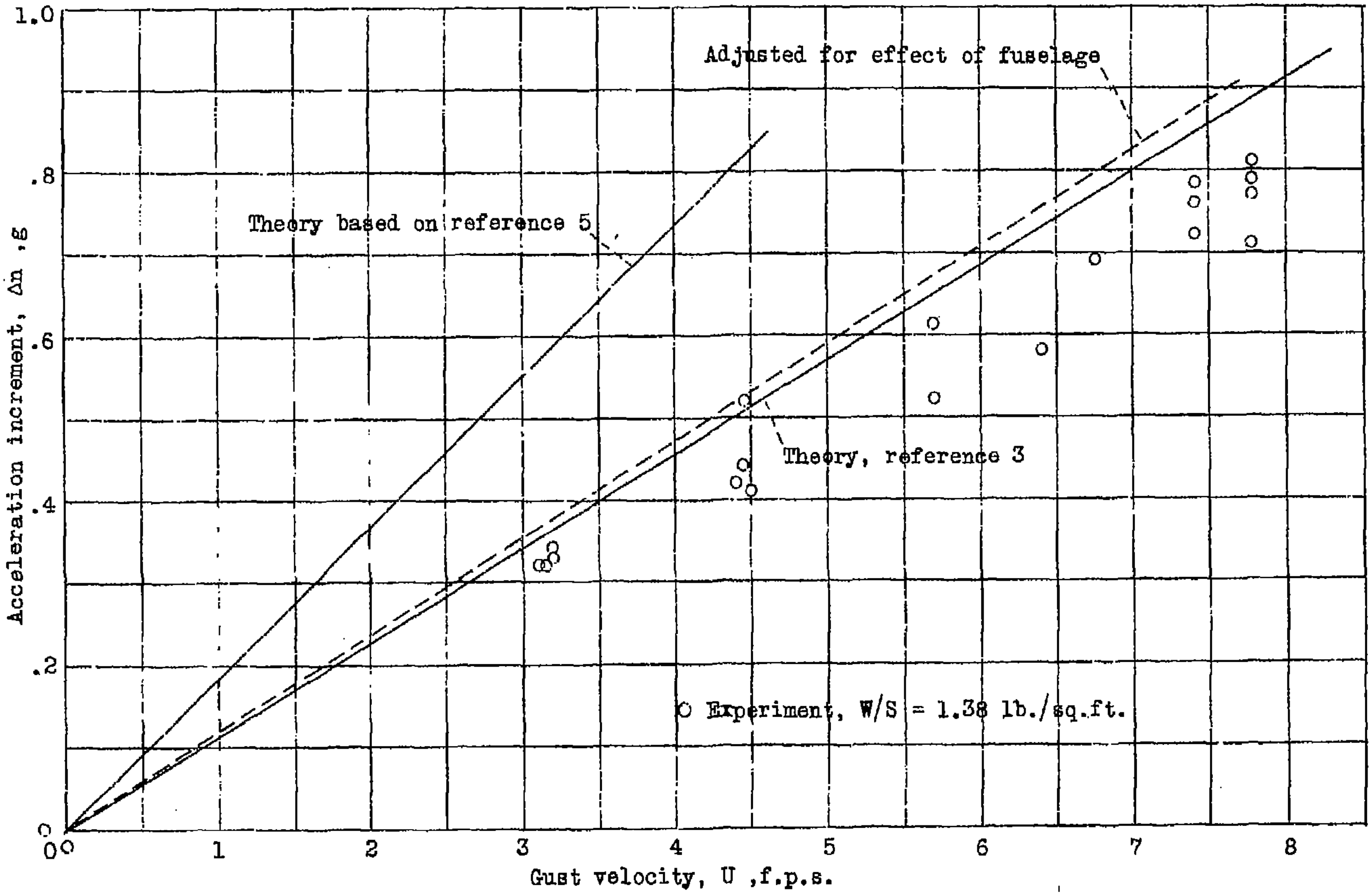


Figure 14.- Variation of acceleration increment with gust velocity. Circular-tip wing; A,2.18, Sharp-edge gust.

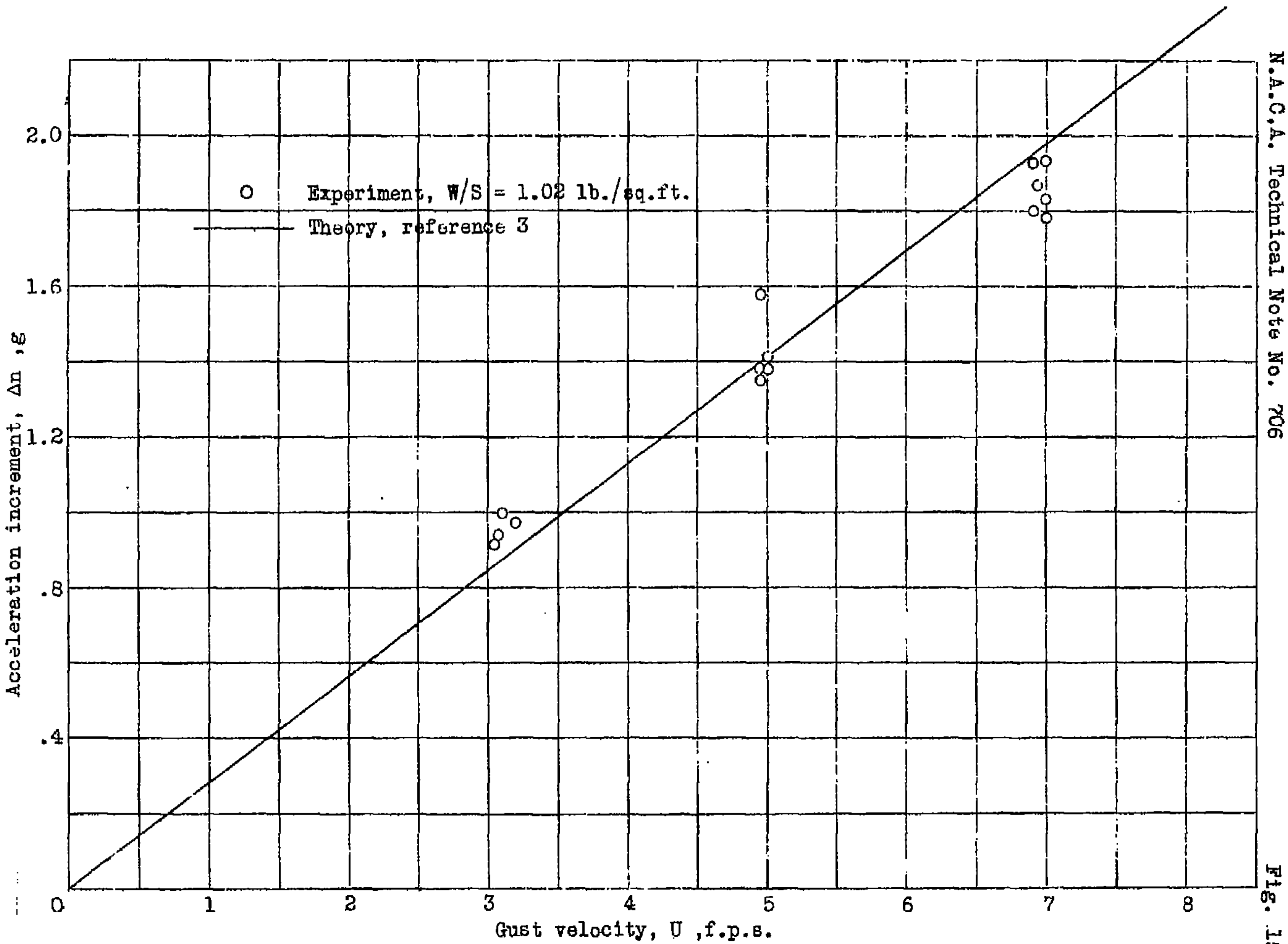


Figure 15.- Variation of acceleration increment with gust velocity. Skeleton fuselage; Square-tip wing; A, 6.73; Sharp-edge gust.

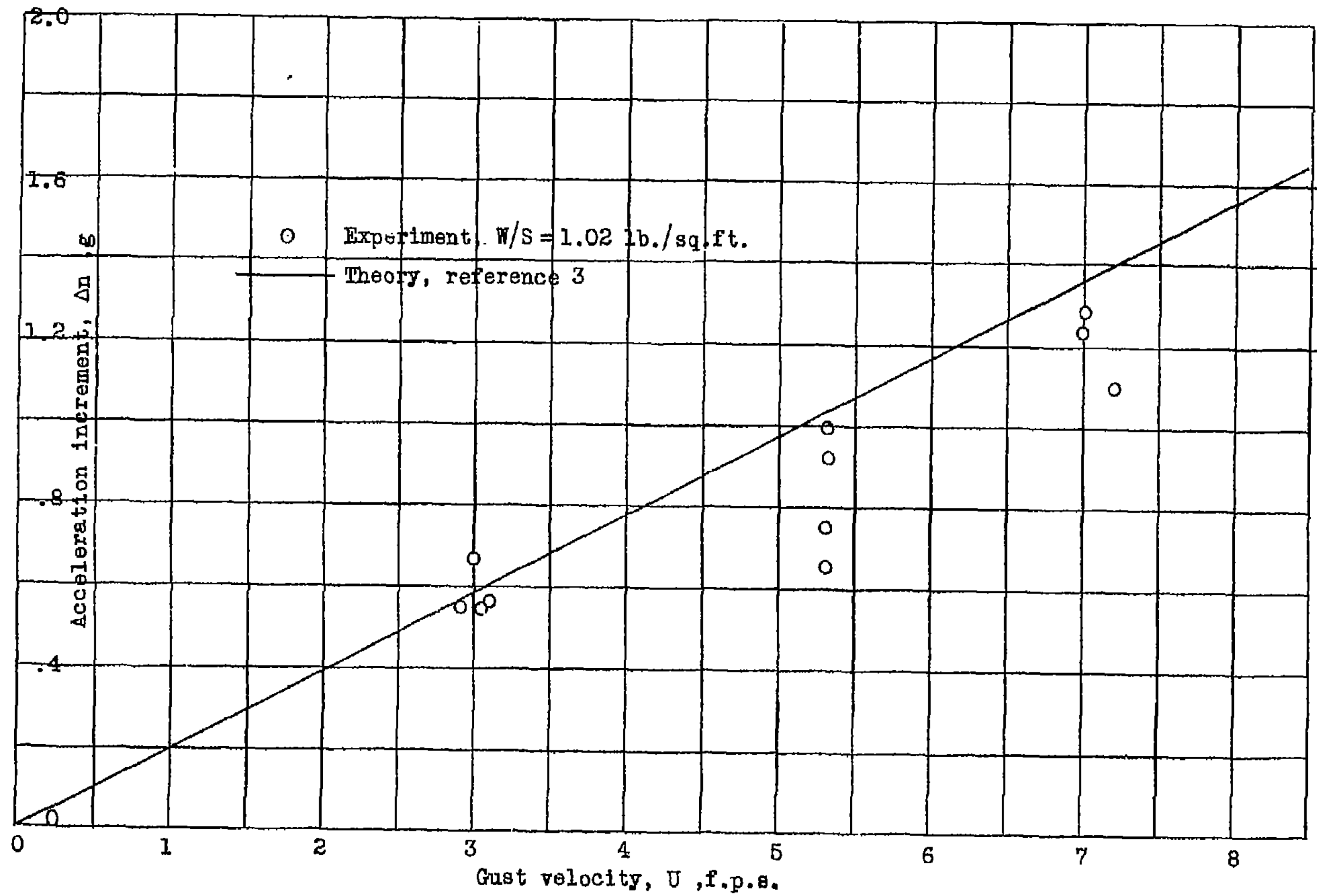


Figure 16.- Variation of acceleration increment with gust velocity. Square-tip wing; A,6.73; Gradient gust.

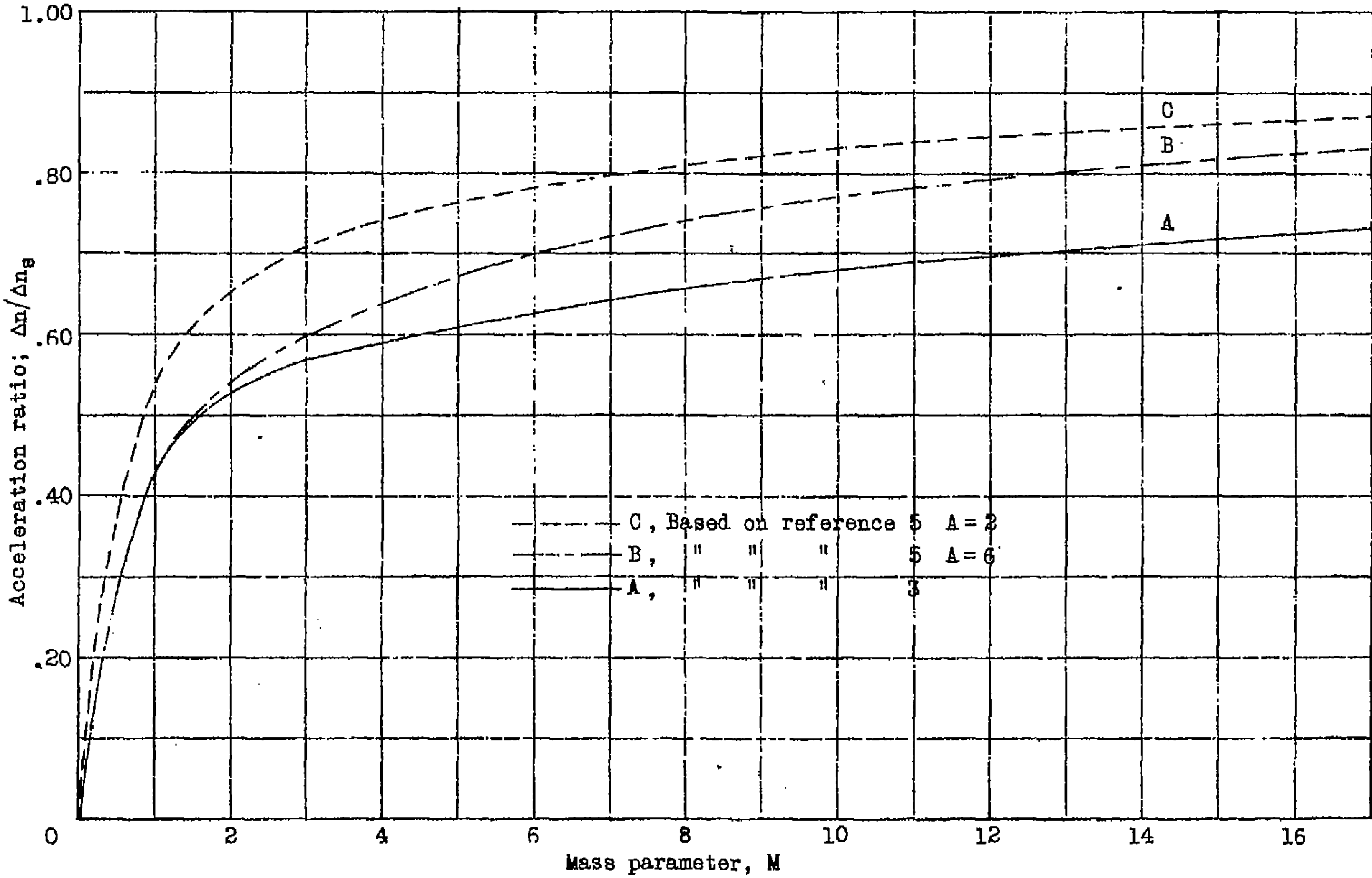


Figure 17.- Variation of acceleration ratio, $\Delta n/\Delta n_s$,with mass parameter, M ,for a sharp-edge gust.

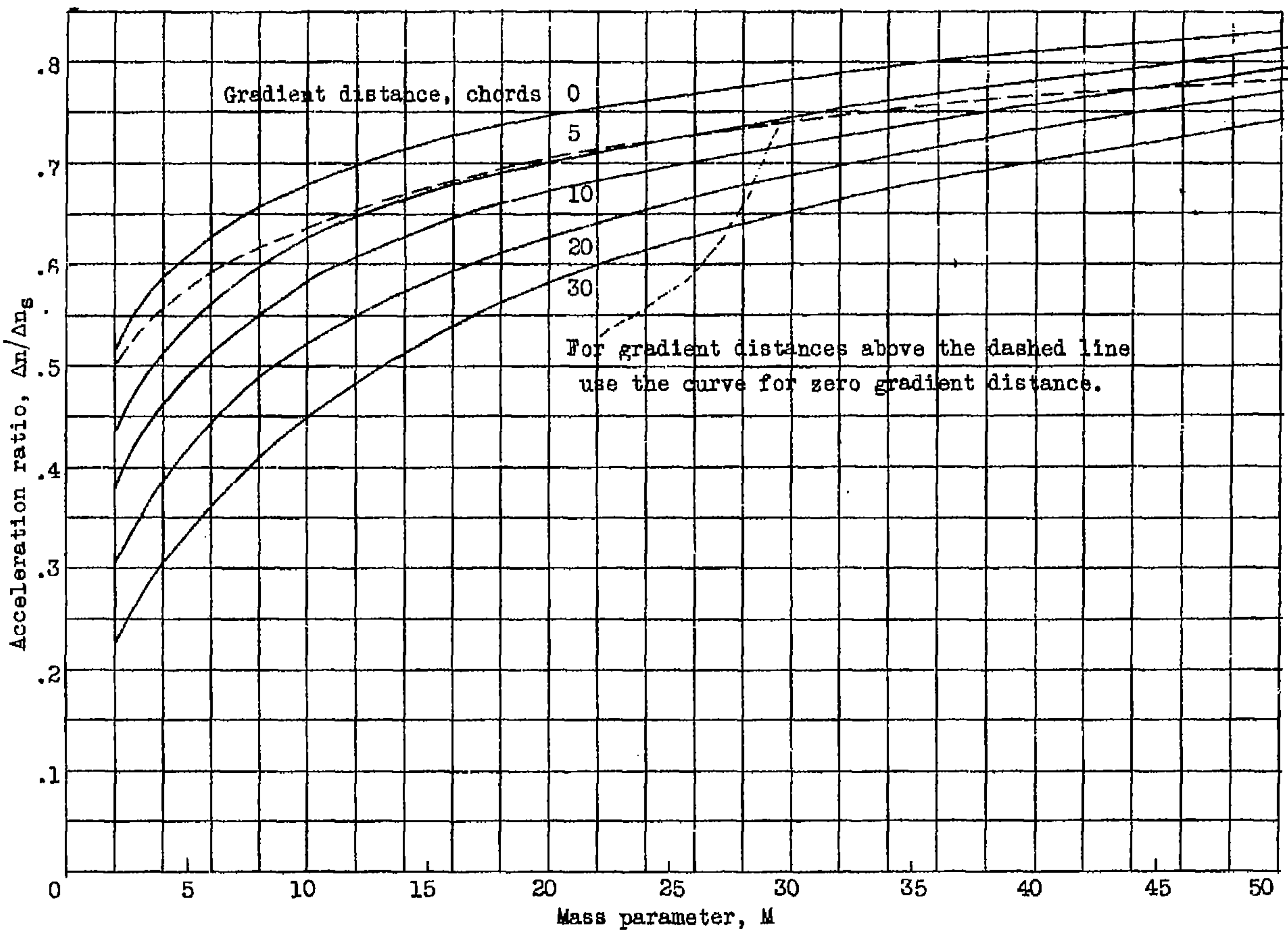


Figure 18.- Acceleration ratio as function of the mass parameter M, with the gradient distance as parameter.